Effects of organic–mineral soil mixtures and increasing temperature on the respiration of coniferous raw humus material

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A marked stimulation of the decomposition of L, F, and H layers of a podzol organic horizon was found when these materials were mixed with mineral soil from the B horizon. However, decomposition was much more enhanced by increasing the temperature of these materials. The potential benefits of forest plantation site preparation by deeply mixing the surface organic horizon with underlying mineral soil are discussed.

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On a observé une stimulation marquée de la décomposition des horizons organiques L, F et H d'un podzol après leur mélange avec le sol minéral de l'horizon B. Cependant, la décomposition a augmenté bien davantage quand on a haussé la température de ces matières. On discute des bénéfices possibles de la préparation des emplacements forestiers pour la plantation par le mélange en profondeur de l'horizon organique de surface avec le sol minéral sous-jacent.

Introduction

Northern forest ecosystems generally accumulate organic matter throughout the rotation, and this tendency becomes more marked with increasing altitude (Kira and Shidei 1967) and latitude. This accumulation has been attributed to decreasing temperature (Viro 1963) and increasing additions of higher carbon/nitrogen ratio materials (Turner and Long 1975). The organic accumulation causes abnormalities in nitrogen mineralization (Florence 1965), inhibition of microbial decomposer activity by polyphenols (Lamb 1976) produced in litter by trees growing on soils which are deficient in available nitrogen and phosphorus (Davies *et al.* 1964), and the competitive advantage of mycorrhizal fungi over microbial decomposers (Gadgil and Gadgil 1971, 1975). The process of humus accumulation and consequent insulation by the organic material on the soil surface, which tends to produce cooler rooting substrate and shallower root penetration, has been seen as a self-accelerating chain reaction (Siren 1955; Von Zezschwitz 1968). To reverse what is seen as a deleterious humus accumulation various silvicultural operations have been suggested such as thinning (Roberge *et al.* 1970; Piene 1978), burning (Siren 1955), and fertilization with chemicals which alter the acidity of the humus (Mahendrappa 1978).

Harvesting and other mechanisms of forest canopy removal warm the organic horizon and work to reverse the accumulation process, although Siren (1955) felt that, without the application of fire between rotations in northern coniferous forests, the accumulation process was not reversed adequately. On the other hand, there is increasing concern regarding nutrient removals from forest sites by whole-tree harvesting (White 1974) and by leaching when herbicide treatment prolongs the period of canopy removal (Likens *et al.* 1970). Forest ecosystems, normally thought of as nutrient conservative, have been shown to be prone to considerable nutrient losses during the early stand establishment stage (Vitousek and Reiners 1975; Bormann *et al.* 1976), and the importance of early canopy establishment by successional species in regenerating cutovers, to attain steady-state nutrient cycling as quickly as possible, has been stressed (Marks and Bormann 1972; Marks 1974).

The influence of low soil temperatures on the growth rate and nutrient uptake of establishing forest crop species has been demonstrated (Heninger and White 1974; Bertenshaw 1978) and humus removal preliminary to planting has been used to increase mineral soil temperatures (Dobbs and McMinn 1973). However, the deleterious effect of humus removal from the planting site on the nutrient relations of the growing crop has also been demonstrated (Nyland *et al.* 1979). Mixing of the organic layers with the underlying mineral soil has been found to increase soil temperatures and enhance tree growth when compared with humus removal or burning (Tubbs and Oberg 1966; Burns and Hebb 1972; McMinn 1974, 1976). Cultivation and the injection of organic material into mineral horizons on forest sites, thought not to be feasible in the past (Nickerson 1956; Tamm and Pettersson 1969), have become a fact as a

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result of the scarifying effects of harvesting equipment and the use of an assortment of plows, choppers, crushers, and cultivators in site-preparation operations.

Although there is little definitive literature on the subject, the physical mixture of forest humus with mineral soil is generally understood to enhance the decomposition of organic matter on forest sites, and there is some evidence from model laboratory systems that microbial activity on organic substrates is stimulated by the presence of clay minerals (Lynch and Cotnoir 1956; Stotzky 1966*a*, 1966*b*). The effect of increased temperature on forest humus decomposition is known (Salonius 1978). This study was designed to compare the stimulation of forest soil decomposing microorganisms, by mixing humus and mineral soil, and by increasing temperature.

Materials and methods

Fresh litter (L), fermentation (F), and humus (H) layers of the organic horizon and the mineral (B) horizon were sampled under feather moss (*Pleurozium schreberi* (BSG.) Mitt.) in a 60-year-old black spruce (*Picea mariana* (Mill.) B.S.P.) site at the Acadia Forest Experiment Station in central New Brunswick. The mineral (B) horizon is a podzolic sandy loam whose clay fraction is predominantly illite (Brydon 1958). These materials, after being sieved through 4-mm-mesh screens, were stored moist in polyethylene bags at 4°C in darkness until used in the laboratory (Salonius 1978).

The organic layers and the mineral B horizon were studied either separately or in various mixtures in a Warburg apparatus where oxygen uptake was measured. The separate materials and the various mixtures were established at the start of the experiment and were carried through a progression of increasing temperatures (10, 20, 30, and 40°C) for 12 days at each temperature in Warburg flasks. The total amount of organic material in the Warburg flasks was always equivalent to 0.5 g ovendry material and consisted of equal proportions by weight when a mixture of three organic layers was present. The amount of mineral (B) horizon material in the Warburg flask was always equivalent to 2 g ovendry material whether studied alone or in mixtures with the various organic layers. All soil materials were studied at field moisture levels, which approximated field capacity or 33 kPa moisture tension. Moisture contents remained stable during the 48-day incubation. Potassium hydroxide (5%) solution was held in the side arms of the Warburg flasks to remove respired CO_2 so that oxygen uptake could be manometrically measured. The KOH solution was removed by suction and replaced with fresh solution at the end of each 12-day incubation period to ensure that the solution would not become saturated with CO_2. The solution replacement required about 1 h during which time the water bath, in which the flasks were incubated, was adjusted to the next higher temperature in the progression. Oxygen uptake rate was measured during 6 h of each day and the manometers were open to atmospheric gas exchange for the remaining 18 h. Respiration of duplicate flasks of organic–mineral soil mixtures was measured directly while respiration of duplicate flasks of the same materials, separated, was summed arithmetically for comparison to assess the effect of mixing.

Results

Respiration (oxygen uptake) of organic layers and mineral soil studied in separate flasks and in mixtures is graphically presented in Fig. 1. Mean (12-day) respiration of the various material combinations at various temperatures is presented in Table 1. The results show, after analysis by Student's *t*-tests, that the only significant increase in respiration at 10°C was when there was a physical mixture of the L, F, and H layers of the organic horizon (Table 1). The inclusion of B horizon mineral soil in the mixture did not further stimulate respiration at 10°C. There were consistently significant increases in oxygen uptake produced by mixing the organic layers with mineral B horizon in all cases at 20 and 30°C and a trend to enhanced oxygen uptake by mixing at 40°C although the latter increases were not consistently significant (Fig. 1 and Table 1). In the treatments in which L, F, H, and B materials were all considered, either by arithmetic summing or actual physical mixture, there was generally increasing respiration as the mixture became more complex. Although there appears to be considerable stimulation of oxygen uptake by mixing the organic and mineral soils especially at 20, 30, and 40°C, this enhancement is much smaller than that produced when these materials are carried through the progression of increasing temperatures.

Discussion

Respiration (oxygen uptake) is indicative of microbial decomposition of organic matter and the release of plant nutrients into the soil solution. Enhanced oxygen uptake at 10°C when the L, F, and H layers were mixed together and not when the individual layers were mixed with the B, is in agreement with former work (Salonius 1978) which showed that 10°C was the only temperature studied at which the physical mixture of the various layers of the organic horizon produced enhanced respiration. This enhancement may be due to a more diverse population (Florence 1967; Salonius 1981) operating on the substrates in the mixture of organic layers. In the field with the vertical stratification of the L, F, and H layers microbial populations, which have developed on the substrates in the individual layers, do not normally have physical access to the organic substrates in the other layers, and these populations have been found to be characteristic of the individual layers in which they are found (Söderström and Bååth 1978). At the lower temperature (10°C), which occurs in the field, the increase in respiration may be due to new substrate–organism proximities. However once the temperatures are higher (20°C and

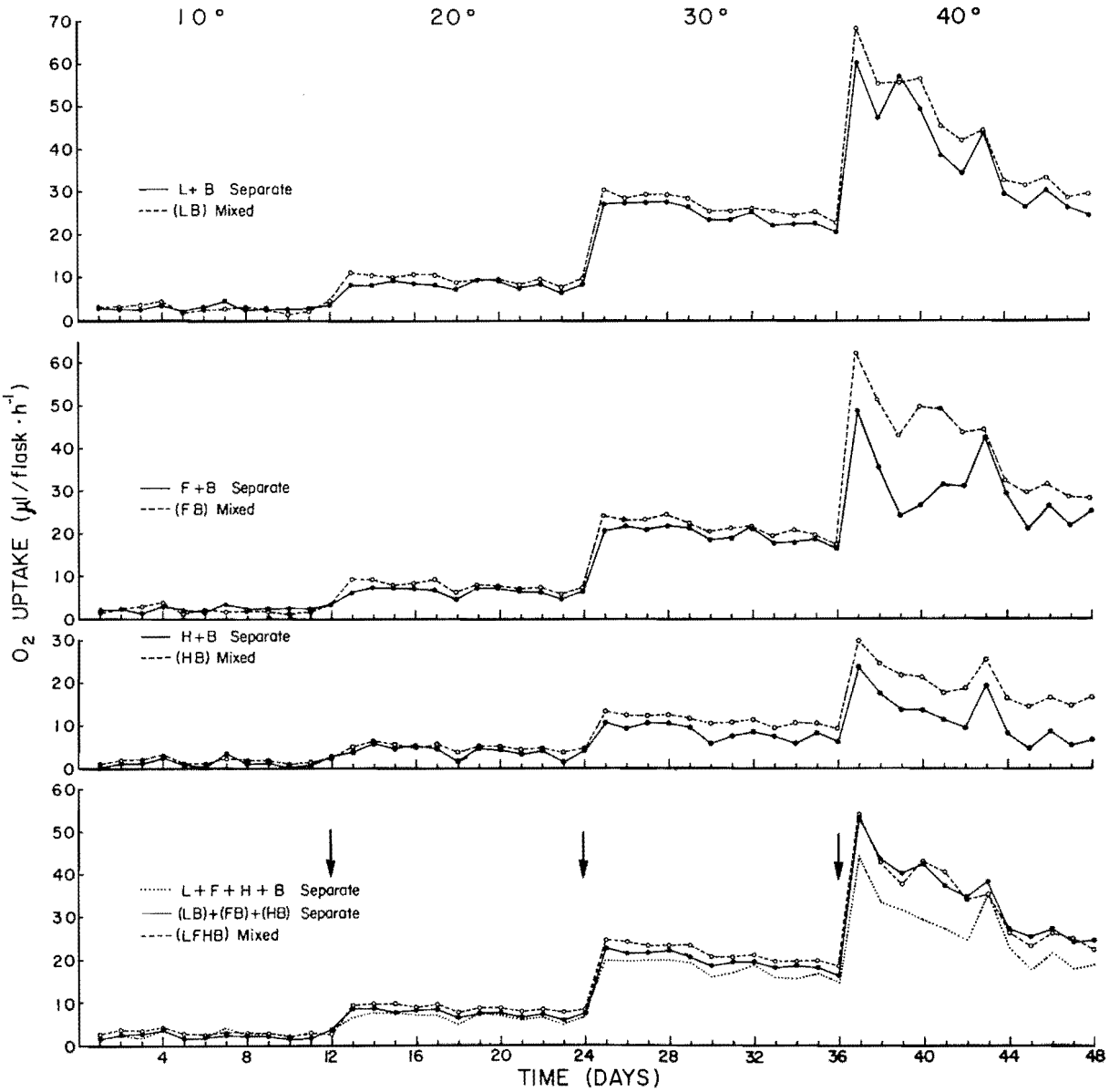

FIG. 1. Respiration of litter (L), fermentation (F), humus (H), and mineral soil (B) materials separately and mixed which were carried through a progression of increasing temperatures (arrows indicate points of change of temperature).

above) than those normally encountered, there is such a temperature-driven metabolic stimulation that any enhancement of overall soil microbial metabolism, by increased species diversity or unprecedented proximity of specific substrates to specific organisms, may be undetectable. Anderson (1978) has discussed effects on soil organisms of the differences in structural complexity that are found in the different organic layers. He found that species diversity increased when there was a greater diversity of microhabitats. The mixing of organic and mineral horizons creates a variety of new microhabitats, which are quite unlike those in the stratified and partitioned organic and mineral horizons in the forest. Stotzky's (1966*a*, 1966*b*) observations that clay colloids may act to buffer the environment of microbial decomposers, may partly explain the enhanced respiration observed in this study when mineral and organic horizons were physically mixed. The buffering of the soil environment, against toxic accumulation of metabolic end products of a rapidly developing population,

TABLE 1. Respiration by separate and mixed horizon samples

Layer	Mean O_2 uptake (μL/flask · h^{-1})*			
	10°C	20°C	30°C	40°C
L + B separate†	2.93(0.60)*a*	8.42(0.66)*b*	24.76(0.49)*d*	39.12(1.08)*f*
(LB) mixed‡	2.74(0.46)*a*	9.71(0.47)*c*	26.77(0.77)*e*	43.47(1.31)*f*
F + B separate	2.50(0.48)*a*	6.70(0.37)*b*	19.55(0.44)*d*	30.58(5.61)*f*
(FB) mixed	2.30(0.87)*a*	7.78(0.47)*c*	21.41(0.31)*e*	41.28(2.95)*g*
H + B separate	1.23(0.51)*a*	3.95(0.42)*b*	8.30(0.91)*d*	11.91(1.10)*f*
(HB) mixed	1.44(0.43)*a*	4.79(0.26)*c*	11.20(0.49)*e*	19.85(1.18)*g*
L+F+H+B separate (LB)+(FB)+(HB) separate − mixed (LFHB) mixed	2.22(0.38)*ab*	6.53(0.25)*c*	17.55(0.51)*f*	27.21(2.30)*i*
	2.16(0.40)*a*	7.43(0.18)*d*	19.79(0.24)*g*	34.92(0.92)*j*
	2.62(0.77)*b*	8.53(0.61)*e*	21.54(0.70)*h*	34.27(1.20)*j*

NOTE: Figures within the groupings (L,F,H,LFH) with the same letter are not significantly different at the 1% level of probability by Student's *t*-test. Figures in parentheses are mean differences between replicate treatments during the 12-day incubations.

*Microlitre per gram organic material + 4 g B horizon (mineral soil) material per hour (12 day means).

†Materials separated by + sign had respiration calculated from results in separate duplicate flasks.

‡Materials inside parentheses had respiration measured on the mixture in duplicate flasks.

may be much more important to the more active populations at 20, 30, and 40°C than to the less active population at 10°C. This may explain why the inclusion of B horizon mineral material at 10°C had little effect. The stimulating effect of soil colloids generally on substrate metabolism and microbial growth has been elaborated on in a recent review by Burns (1981).

The greater stimulus to microbial decomposer activity by increasing temperature than by mixing may have some relevance to forest site preparation strategies. After harvest, in the absence of a forest canopy, organic soil surface temperatures up to 50°C and increases in temperatures within the humus horizon have been recorded (Roberge *et al.* 1970). Intermittent drying of the entire organic horizon after harvest (Frater 1980) and subsequent wetting and drying, and freezing and thawing cycles (Arsjad 1966; Arsjad and Giddens 1966; Jager 1967; Van Schreven 1968) also increase humus decomposition rates. This increased decomposition, especially when canopy reestablishment by noncrop species is controlled by herbicides and fire, can decrease the thickness of the humus layer to the extent that underlying mineral soil is exposed (Suffling and Smith 1979).

The potential loss of nutrients into drainage water and its vertical movement as a result of this magnified decomposition due to prolonged unshaded humus exposure has led Kimmins and Hawkes (1978) to recommend that whole-tree harvesting, slash burning, broadcast burning, broadcast drag scarification, and broadcast herbicide application not be carried out on nutrient-poor sites. Many of the deleterious effects of enhanced decomposition of surface humus and subsequent vertical movement of potential nutrients for the future crop are caused by maintaining that humus unshaded on the surface while the newly planted crop has not yet developed a root system adequate to utilize the nutrients brought into solution. Many silvicultural operations discourage the reestablishment of competing vegetation which could hold those nutrients on the site (Marks 1974).

It is possible that these postharvest nutrient losses may be partially avoided by a site preparation method which mixes the surface organic materials deep into the mineral soil. A large proportion of the nutrient-rich humus would then not be exposed to such decomposition stimulating high temperatures and wetting and drying cycles. This deep mixing would expose the mineral soil to high temperatures and wetting and drying cycles, but the very low percentage of organic constituents in the mineral soil would make its increased decomposition relatively unimportant. Raising mineral soil temperatures, in which considerable early rooting takes place, has resulted in the enhanced plantation growth observed by Dobbs and McMinn (1973). Deep mixing would avoid the drying of the humus layer (Frater 1980) that can be lethal to planted seedlings which have not established adequate rooting in the mineral soil (where a more consistent water supply is available); and it would avoid the nutrient removal from the proximity of the developing plant roots, which is currently done by many scraping types of site preparation equipment designed to provide exposed mineral soil for planting, and control the competing vegetation (McMinn 1974). Mixing the surface organic horizon deeply with mineral soils may also produce a deeper rooting habit than that usually found with many conifers growing in raw humus sites (Weetman 1968;

Kimmins and Hawkes 1978). Harvey *et al.* (1979) have described the beneficial aspects of decayed wood as a rooting habitat, and mixing has the effect of injecting wood and other organic matter into unprecedented depths of the forest soil profile. McMinn (1976) has reported on the feasibility of the use of existing agricultural rototilling equipment and referred to the possibility of modifying such equipment for use in forest site preparation.

Conclusions

Increasing the temperature of forest soil organic materials stimulates their decomposition much more than does mixing them with the underlying mineral soil. Site preparation of planting spots or strips by mixing the surface organic horizon deeply into lighter textured mineral soils will avoid the usual heating, wet–dry cycles, and excessive decomposition of the surface humus, because a large proportion of the organic material is buried. This type of site preparation will bring to the surface and warm mineral soils to more optimum temperatures for root growth.

Lysimeter studies, to compare the nutrient content of drainage water from tilled soil columns with that from soil columns which are undisturbed but have similar vegetation control, would serve to assess the long-term consequences of tilling on site productivity potential. Full-rotation growth studies on trials such as those of McMinn (1974) will also be necessary to assess the long-term effects of altering decomposition and nutrient cycling rates early in the rotation.

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